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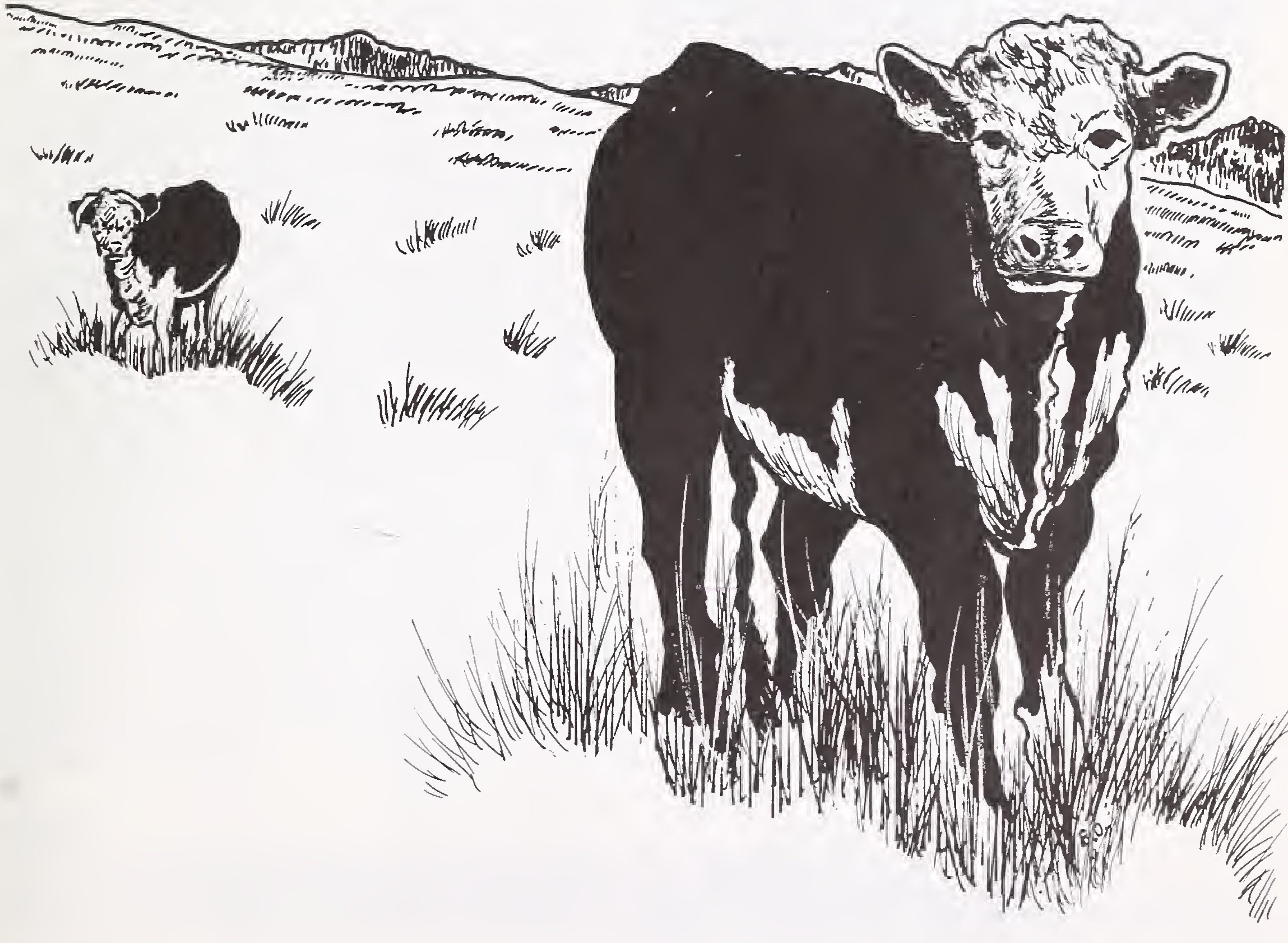
SEEDING AND FERTILIZING TO IMPROVE HIGH-ELEVATION RANGELANDS

William A. Laycock



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RESEARCH SUMMARY

Seeding and fertilizing are two tools available to range managers to increase productivity on rangelands. Even though some of the earliest range management research in the United States was conducted on high-elevation rangelands, relatively little range research is now being conducted on these areas. The advent of strip mining and other activities which drastically disturb rangelands has revived interest in seeding and fertilizer research. This paper summarizes the available literature on seeding and fertilizing high-elevation rangelands to assist those now charged with revegetating or increasing productivity on such areas and also as an aid to further research.

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Cover caption:
Cattle on a high-elevation big sagebrush site in northeastern Utah that was plowed and seeded to a mixture of crested wheatgrass and smooth brome. Grass production on the seeded area averaged 1 500 to 1 700 kg/ha. Total grass production in the native sagebrush stand was only 450 to 500 kg/ha.

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INTRODUCTION

Seeding and fertilizing are two of the tools available to range managers to increase productivity of rangelands. Even though some of the earliest range management research in the United States was conducted on high-elevation rangelands (for example, Cotton 1905, 1908; Griffiths 1907; Sampson 1913, 1921), relatively little range research is now being conducted on these mountain areas.

The advent of strip mining and other activities which drastically disturb rangelands has revived interest in seeding and fertilizer research. Much of the more recent research, however, is being done at lower elevations and has ignored the earlier research. Many recent studies have examined methods of planting, species adaptability, fertilizing, and similar areas which duplicate earlier research. The objective of this paper is to summarize the available literature on seeding and fertilizing high-elevation rangelands in the western United States and Canada as an aid to those now charged with revegetating or increasing productivity of such areas and to further research. The lower elevation and precipitation limits of the vegetation types included are difficult to define but, in general, are those of the lower limits of the ponderosa pine type. Other vegetation types include openings or burns in higher elevation forest communities, open grasslands dominated by species of fescue (*Festuca* spp.), aspen, "mountain meadows," and alpine. Data from vegetation types or similar types in other parts of the world are included when appropriate to make comparisons or to illustrate specific points.

SEEDING

Even before the turn of the century, the problems on overgrazed mountain rangelands were beginning to be recognized. In 1897, the U.S. Department of Agriculture conducted experiments in the Big Horn Mountains of Wyoming which demonstrated that timothy[1] could be successfully seeded at an elevation of 7,000 feet (2 130 m) (Griffiths 1907). Experiments were started in 1901 on Rattlesnake Mountain near Prosser, Wash., and, in 1902, at the Wenatchee Mountain Station to determine what species of grasses could be established on the mountain range areas (Cotton 1905, 1908).

Sampson recognized that natural succession might not accomplish rehabilitation of overgrazed mountain rangelands quickly enough and began experiments in 1907 in Oregon to determine which grass species were best adapted, what time of year was best for seeding, and what cultural methods should be used (Sampson 1913). In 1912, he established two experimental areas at an elevation of almost 10,000 feet (3 050 m) on what is now the Great Basin Experimental Range of the Forest Service in central Utah on which he planted timothy, Kentucky bluegrass, orchardgrass, and smooth brome (Keck 1972). Many other trials followed as he continued his work to find species adapted to the harsh climate of high-elevation areas (Sampson 1921, 1923). Other early work in Utah showed that the abundance and character of grasses and forbs on high mountain watersheds could mean the difference between normal streamflow of clear, usable water and abnormal, disastrous mudrock floods (Reynolds 1911). Since that time, many experimental plantings have been made and numerous publications have been issued recommending such items as species, seeding methods, and time of seeding for various regions, elevations, and range types in the western United States. Those dealing with high-elevation rangelands are summarized in this paper.

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[1]Scientific names of most species are listed in the appendix. Scientific names of those species not in the table are included where appropriate.

Reasons for Seeding

Seeding on high-elevation rangelands generally is done to increase production of species palatable to livestock or wildlife, or to maintain or improve watershed stability. Other reasons for seeding include: replacement of weedy or low-producing species with better species; extending the period of green herbage availability; increasing the nutritive content of herbage; and providing temporary protective watershed cover for timberland disturbed by fire or logging, or altered by reshaping for use as ski slopes.

Improvement of depleted rangelands by rest, deferment, control of undesirable plants, or other management techniques should be attempted when enough desirable native species are present. The harsh climate, short growing season, and lack of seed source of desirable species on many depleted high-elevation sites often make natural revegetation very slow, however. Artificial introduction by seeding of desirable species often is the only way to speed up the healing process. Where brush or weed species have become dominant on the area, control measures usually are necessary before forage production can be increased by managing the native stand or by seeding.

Suitability of the site chosen to increase production sufficiently after seeding to warrant the investment is another factor in the decision to seed or not. Seeding is expensive and costs are rising rapidly. Methods of calculating seeding costs and returns have been described by Lloyd and Cook (1960) and others. Full consideration must also be given to the possible beneficial or detrimental effects of seeding on wildlife habitat and the possibility of erosion in case of seeding failure or runoff caused by high-intensity storms before plants become established.

A working group has been formed in Colorado dealing with the subject of revegetation of high-altitude disturbed lands. This group has sponsored publication of a bibliography pertinent to disturbance of alpine and subalpine lands in the southern Rocky Mountain (Steen and Berg 1975) and has held three workshops on the subject (Berg and others 1974; Zuck and Brown 1976; Kenny 1978). The group has also sponsored high-elevation tours and some limited research on high-elevation plant materials development (Kenny and Cuany 1978).

SEEDING TO INCREASE PRODUCTION

On many depleted high-elevation sites, seeding with high yielding and adapted species can greatly increase production of palatable herbage. Sites selected for seeding should offer a good possibility for success and the species planted must be matched to the soil, site, climate, and type of animal that will graze the area. Only a small portion of the seeding literature presents comparative forage production data on seeded and unseeded areas. Table 1 summarizes some representative figures on peak aboveground standing crop of grass on comparable seeded and unseeded areas. Seeded areas generally produced 2 to 10 times as much grass as comparable unseeded areas.

Table 1.--Peak aboveground standing crop of grasses on some representative seeded and unseeded high-elevation rangeland areas

Location	Type high-elevation rangeland	Yield of grasses (air dry)					
		Unseeded control		Seeded			
				1-3 years		≥ 4 years	
		Lb/acre	*Kg/ha*	*Lb/acre*	*Kg/ha*	*Lb/acre*	*Kg/ha*
Utah (Orr 1957)	Subalpine grassland	340-746	381-836	2,097-4,552	2 350 5 103	--	--
Northeastern Utah (Laycock and Conrad 1981)	High-elevation sagebrush	487-750	546-841	--	--	1,338-1,579	1 500-1 770
Montana (Gomm 1962)	Subalpine grassland	7-97	8-109	68-599	76-671	998-1,319	1 119-1 479
Montana (Gomm 1974)	Openings in lodgepole pine	530-621	594-696	1,113-2,000	1 248-2 242	1,600	1 794
Colorado (Doran 1951)	Openings in aspen	120	135	600-1,200	673-1 345	--	--
Colorado (Hull and Johnson 1955)	Ponderosa pine	469	526	827-1,697	927-1 902	--	--
Northern New Mexico (Lavin and Springfield 1955)	Ponderosa pine	50-200	56-224	1,860	2 085	--	--
Eastern Oregon and Washington	Ponderosa pine	N.A.[1]		750-1,600	841-1 794	--	--
(Rummell and Holscher 1955)	Burns in subalpine forest	N.A.		642-977	720-1 095	--	--
Washington (Smith 1963)	Green fescue	N.A.		690-3,200	773-3 587	860-4,755	964-5 330
East slope Sierra and southern Cascades (Cornelius and Talbot 1955)	Mountain meadows	166-617	186-692	998-4,070	1 119-4 562	--	--

[1]N.A. = data on unseeded area not available.

Peak aboveground standing crop has been the standard method of estimating production on rangelands. Such estimates are lower than, but can be correlated with, total aboveground net production (Kelly and others 1975; Singh and others 1975). Pieper and others (1974) have shown that peak herbage weight lasts only a short time and that the amount of herbage available for grazing animals for most of the grazing season is considerably less than that present at the peak.

SEEDING TO EXTEND THE GRAZING SEASON

Because many introduced cool-season grasses start growth considerably earlier in the spring than native species, seeded ranges can often be used to extend the grazing season (Currie 1969). Some introduced species also are green later in the summer or produce substantial regrowth in the fall and thus can extend the season of high-quality forage.

SEEDING TO IMPROVE SOIL AND WATERSHED STABILITY

On seedings for control of erosion, the best adapted species that will establish stands should be planted (Steen and Berg 1975). Early studies (Reynolds 1911; Forsling 1931; Bailey 1934) recognized the importance of restoring a good cover of vegetation on depleted mountain slopes to help prevent runoff and further erosion. Later studies have verified that if vigorous stands of adapted species are established, runoff and erosion can be reduced or eliminated.

On a subalpine rangeland, dominated by letterman needlegrass (*Stipa lettermanii*) on the Great Basin Experimental Range in central Utah, contour trenching and seeding in 1953 increased total ground cover and completely eliminated runoff and erosion from a depleted area (Meeuwig 1960). Species seeded were smooth brome, meadow foxtail, orchardgrass, mountain brome, and meadow brome. The seeded stand is still in excellent condition and no measurable runoff has yet occurred from the watershed (A. P. Plummer, personal communication). Grazing has not been allowed on the area since seeding.

On another watershed on the Great Basin Experimental Range, Orr (1957) found that soils on seeded and untreated areas were similar in bulk density, infiltration, runoff, and sediment production 3 years after seeding. The area was seeded with a mixture of smooth brome, tall oatgrass, meadow foxtail, reed canarygrass, orchardgrass, mountain brome, and alsike clover and was protected from grazing for 3 years. A study made after 4 additional years, during which moderate grazing had taken place (Meeuwig 1965), indicated that average protective cover by plants and litter was significantly less on the seeded plots (63 to 74 percent) than on the native plots (70 to 85 percent). The surface soil of the seeded plots had significantly greater bulk density and significantly less capillary pore space than adjacent unseeded areas, and soil eroded from infiltrometer plots was greater on the seeded plots. Meeuwig (1965) concluded that disking and seeding can be used to increase usable forage in subalpine ranges, but that areas treated should be chosen with caution because of the potentially damaging effect on infiltration and soil stability if ground cover on seeded areas is not maintained at a level sufficient to protect the soil.

Broadcast seeding of grass on burns is a standard technique for quickly restoring protective watershed cover. In the Black Hills of South Dakota, timothy, Kentucky bluegrass, and smooth brome were broadcast seeded from a helicopter after a burn in the ponderosa pine type (Orr 1970). Total ground cover of 60 percent, which reduced runoff and erosion to tolerable levels, was achieved on some sites within the first year and on the entire area within 4 years.

High elevation areas that have had severe soil disturbance from mining and similar activities pose special problems for revegetation. Most research on revegetation of badly disturbed areas is recent and thus results are rather short-term in nature. Results from short-term seeding studies can be misleading and of little value for long-term stability.

One activity which can badly disturb small areas is clearing for ski trails. In Washington, Klock (1973) recommended the following steps to insure successful revegetation of a newly cleared run:

1. Topsoil conservation.
2. Selection of adapted plant species.
3. Testing of soil fertility.
4. Correct time of seeding--usually as soon as possible.
5. Irrigation to get germination and emergence if necessary.
6. Covering seed and fertilizer with soil.
7. Mulching.
8. Control of subsequent soil disturbance.
9. Use of maintenance fertilizer.
10. Judging success no sooner than after two growing seasons.

Welin (1974) concluded that ski slopes can be successfully revegetated if not too steep.

Areas disturbed by strip mining at high elevations pose special rehabilitation problems because of the large scale of the operations and the difficulty of replacing suitable soil materials for plant growth. The recommendations outlined above for rehabilitating disturbed ski runs generally apply to revegetating spoil banks or other areas disturbed by strip mining. Especially important are conservation and replacement of topsoil material. In addition, spoil piles must be shaped and smoothed before seeding. Cook and others (1974) recommended methods, species, and special precautions necessary to revegetate mined areas in the ponderosa pine, mountain brush, aspen, and other subalpine and alpine vegetation types in the western United States.

On a copper-cobalt mine in the lodgepole pine type in Idaho, Farmer and others (1976) tested a range of potential species, soil treatments, and fertilizers to find the combination that would best provide an acceptable plant cover in the acid mine wastes. Replacement of native topsoil or subsoil and a combination of fertilization and mulch significantly increased production of all mixtures of native and introduced species. Cook and others (1970) recommended mixtures of grasses including smooth brome, pubescent wheatgrass, tall fescue, orchardgrass, and Italian ryegrass for stabilizing road cuts at high elevations in Utah where precipitation was between 20 and 40 inches (50 and 100 cm) annually. Mulches helped establish better stands of the seeded species.

Based on the few available published reports on methods and species for revegetating alpine tundra areas disturbed by mining and other factors, Brown and others (1978)

recommended planting mixtures of several species and rates of 25 to 50 pounds per acre (28 to 56 kg/ha). Their review also indicated that transplanting of alpine sod in the fall should result in successful establishment of most species. Transplanting experiments were described by Brown and Johnston (1978).

Monsen (1975) discussed recent advances in techniques for selection of plants to rehabilitate disturbed areas. He recommended planting of mixtures to accommodate variation within the disturbed areas, and use of native species where possible. The use of native versus introduced species will be discussed later.

Species for Seeding

GRASSES

The appendix summarizes the species recommended by various investigators for high-elevation rangeland vegetation types in the western United States. Only a few grass species are consistently recommended for most areas. Smooth brome was the only grass species that has been recommended as a well-adapted, and productive species on all areas, including the drier ponderosa pine type. On the moister and cooler higher elevation rangelands, such as aspen, openings or burns in high-elevation forests, and other mountain herblands, other grass species regularly recommended include: meadow foxtail, mountain brome, tall oatgrass, timothy, and orchardgrass. Mountain brome, a short-lived species (Hafenrichter and others 1968), may produce good stands for only 4 to 5 years and then be replaced by other species (Plummer and others 1955; Bleak 1968). In mountain meadows only two species, meadow foxtail and timothy, were uniformly recommended in addition to smooth brome. Species consistently recommended in the drier ponderosa pine type included crested, fairway, intermediate, beardless, and pubescent wheatgrass in addition to smooth brome. All of these wheatgrasses are well adapted to drier sites. Two wheatgrasses, intermediate and slender, can also be grown at higher elevations, however, and were recommended in some studies. Slender wheatgrass is also a short-lived species that may not persist in stands (Hafenrichter and others 1968).

Most of the species listed in the appendix are recommendations based on expected successful establishment within 2 to 4 years following seeding. Longer term results are not as plentiful. In a high elevation (9,350 ft, 2 850 m) nursery in Idaho fescue grassland area in southwestern Montana, Peterson (1953) reported that only the following grass species maintained vigorous stands over a 10-year period: smooth brome, meadow foxtail, meadow brome, Kentucky bluegrass, slender wheatgrass, and bearded wheatgrass. The first five were recommended as being the most reliable for reseeding similar subalpine areas in Montana. Sixteen species of grasses and legumes produced good stands initially, but had declined substantially by the 10th year. Fourteen additional species suffered severe kill within the first 3 years.

As many as 21 years after seeding, Hull (1974) found that smooth brome, meadow foxtail, and creeping foxtail maintained stands on mountain rangelands in southeastern Idaho, northeastern Utah, and western Wyoming. Intermediate and pubescent wheatgrasses were adapted to intermediate and lower mountain ranges. Other grasses that performed well in the long-term seedings were mountain, subalpine, and Regar brome, timothy, orchardgrass, tall oatgrass, reed canarygrass, and hard fescue (appendix). Legumes and forbs that persisted over long periods included birdsfoot trefoil, crown vetch, alfalfa, bird vetch, and horsemint. Twelve species of grasses and five species of legumes produced only fair-to-poor stands and an additional 25 species of grasses and nine species of legumes failed to produce stands. Mixtures of adapted species generally resulted in better stands than single-species seedings.

To evaluate results over a longer period of time, Hull (1973) examined stands of species seeded experimentally from 1936 to 1939 on depleted and terraced mountain rangelands in northern Utah. By 1971, only smooth brome, tall oatgrass, intermediate wheatgrass, and red fescue still formed fair-to-excellent stands. The other 33 species seeded had disappeared or formed only poor stands. The area had not been grazed by livestock since the 1930's when the rangelands were terraced and seeded to restore watershed stability.

Gomm (1974) reported results of seeding trials in various vegetation types in Montana and summarized data not published or available elsewhere. Results of individual trials are not presented here, but they included studies in alpine grassland, subalpine forest and grassland, Douglas-fir-larch forest, lodgepole pine-Douglas-fir forest and grassland, and western ponderosa pine forest and grassland areas.

Two years after seeding on a copper-cobalt mine in the lodgepole pine type in Idaho, orchardgrass and timothy produced the highest density of any species tested in mixtures of several species (Farmer and others 1976). Other introduced species that performed reasonably well in the mixtures were timothy and orchardgrass. Squirreltail (*Sitanion hystrix*) and western yarrow (*Achillea millefolium*) were the most successful native species. The wheatgrass (crested, intermediate, western, and bluebunch) produced good stands the first year after seeding, but survival the second year was poor.

Studies of direct seeding and transplanting of individual species or native sod have been conducted on alpine areas on the Beartooth Pateau in Montana disturbed by mining (Brown and Johnston 1978; Brown and others 1976; Brown and Johnston 1976). Species successfully established by either seeding or transplanting included Scribner wheatgrass (*Agropypon scribneri*), slender wheatgrass, meadow foxtail, tufted hairgrass (*Deschampsia caespitosa*), alpine timothy, alpine bluegrass (*Poa alpina*), and spike trisetum (*Triestum spicatum*). The introduced species, meadow foxtail, smooth brome, timothy, intermediate wheatgrass, tall fescue, and orchardgrass were also successfully seeded (Brown and Johnston 1976) and seed is commercially available. In a subsequent study (Brown and Johnston 1978) alpine bluegrass, alpine timothy, tufted hairgrass, and meadow foxtail were the most successful species in transplant studies, with Canada bluegrass also appearing to be adapted.

FORBS AND SHRUBS

Most of the species used to seed mountain grasslands have been grasses. Only a few forbs were reported in

earlier studies (appendix 1). In 1938, 24 native species (13 forbs, five grasses, and six shrubs) were seeded on exposed road cuts in the subalpine and alpine areas (9,500 to 11,800 ft [2 900 to 3 600 m]) in Rocky Mountain National Park (Harrington 1946). Six years after planting, 15 of the 24 species were abundant enough to indicate promise for seeding purposes. Arranged in descending order of relative desirability and success, the species were: spreading golden pea (*Thermopsis divaricarpa*); silky phacelia (*Phacelia sericea*); varileaf phacelia (*Phacelia heterophylla*); rough bent (*Agrostis scabra*); tufted hairgrass; mountain brome; cow parsnip; spike trisetum; cliff jamesia (*Jamesia americana*); alpine bluegrass; cryptantha (*Cryptantha virgata*); western yarrow; American red raspberry (*Rubus strigosus*); sagewort (*Artemisia norvegica* spp. *saxatilis*); and whipple penstemon (*Penstemon whippleanus*). Even though seeding of silky phacelia was quite successful, transplanting of the same species failed.

In 1950, mountain brome, blue wildrye, cow parsnip, and western coneflower (*Rudbeckia occidentalis*) were planted in openings and under aspen canopy at an elevation of 9,000 ft (2 740 m) in central Utah (Ellison and Houston 1958). Three years after planting, plots in the open were much more productive than those under the canopy. The two grasses and western coneflower were productive and successful on all plots. Cow parsnip became established only under the aspen canopy, indicating a strong microclimatic selection which would limit use of this species to moist, cool, or shaded sites.

The practice of planting a mixture of species, including legumes and other forbs, has been given increased attention in recent years. In addition to those listed in the appendix, Plummer and others (1968) listed many other forbs, legumes, and shrubs that are adapted to aspen and subalpine ranges in Utah.

Seeding Methods

This publication is not intended to be a methods handbook for reseeding mountain rangelands. Some consistency, however was found in the available literature that indicated the conditions and methodology necessary for successful seeding.

USING ADAPTED SPECIES

Most of the introduced grasses and some of the native grasses recommended in the appendix are available from commercial seed sources. Where more than one variety of a species is available, the variety best suited to the conditions in the area should be used. The characteristics of the most common grasses and legumes used for seeding in the Pacific Northwest and Great Basin States are described in a Soil Conservation Service Handbook (Hafenrichter and others 1968), in the Oregon Interagency Guide (Anderson, n.d.), and elsewhere.

The Soil Conservation Service has established a number of plant material centers to study and develop grasses and legumes for use in conservation; to determine reliable cultural and management methods; and to get proven materials into production by farmers, ranchers, and commercial growers (Hafenrichter and others 1968). The most recently established plant material center is at Meeker, Colo. (Burdick 1975). This new center is in a large area of high-elevation rangelands and is primarily concerned with testing adapted native species for seeding at high elevations, as well as at lower areas.

Native Versus Introduced Species—Currently, there is considerable controversy over the desirability of seeding native species rather than introduced species, especially for the revegetation of areas disturbed by strip mining. Recommendations and regulations requiring use of native species apparently are based on the assumption that, because a species grew on the site before disturbance, it would be better adapted than introduced species if it were to be put back on the site. There is little evidence to support this assumption, but there are many examples of stands of introduced species maintaining high production and site stability for long periods of time. Many of the earliest stands of crested wheatgrass planted before and during the 1930's are still intact in spite of a long history of heavy grazing. Smooth brome planted by Sampson (1913, 1921) in 1912 at about 10,000 ft (3 050 m) elevation on the Wasatch Plateau in Utah has spread far beyond the original plots and still maintains good stands.

Hull (1973) examined stands of grasses and forbs planted from 1936 to 1939 on depleted and terraced mountain rangelands in Utah. In 1971, smooth brome, tall oatgrass, and intermediate wheatgrass still formed excellent stands and had spread well beyond the area originally seeded. Red fescue still formed fair stands on favorable sites. The remainder of the 25 grass species and 12 forb species originally planted either had disappeared by 1971 or had formed only poor stands. Of the 33 seeded species which failed to produce stands, 11 were native grasses and seven were native forbs. Native grasses, forbs, shrubs, and trees had reinvaded all seeded areas by 1971. In areas where seedings had failed and native species had not reinvaded, annuals still dominated.

The long-term observations in Utah illustrate the importance of establishing a good stand of adapted species as rapidly as possible on disturbed areas. Frequently introduced species are the species most available and best suited to accomplish this. In time, native species will reinvade the seeded area on most sites and again become part of the community.

Species selected for seeding should be those best suited to the site and best fitted to the reasons for seeding. At present, introduced are the best choice in many, perhaps most situations for the following reasons:

1. Introduced species have a long history of improvement and selection for high productivity. Under favorable moisture conditions, well-adapted introduced species usually produce significantly more herbage than do species native to the site.
2. Cool-season, introduced grasses "green-up" considerably earlier than most native species, thus extending the grazing season or taking pressure off of native stands at the vulnerable early growth stage.
3. Palatability of many introduced species can be significantly greater than that of species native to a site.
4. Seed of introduced species is available commercially in quantity and generally at a lower price than seed of native species. Seed of native species is often collected near the site to be seeded at rather high costs per pound. Such seed is often of low quality.
5. Germination rates and ease of establishment tend to be greater for introduced species than for native species.

This difference is especially true when the native seed is collected locally.

6. Grazing resistance and longevity of at least some introduced species are far superior to the species native to the site. For example, crested wheatgrass and smooth brome can survive heavy use, and stands persist for many years. Some of the native species for which commercial seed is available are short lived; for example, mountain brome, slender wheatgrass, bearded wheatgrass, and blue wildrye (Hafenrichter and others 1968).

REMOVING COMPETITION

Competition for moisture from existing plants may completely prevent seedlings of seeded species from becoming established. Various ways to remove or reduce competition include burning, plowing, disking, and chemical control. In general, plowing or disking makes the best seedbed, but this is not recommended on slopes steeper than 20 percent because of the erosion hazard (Hull and others 1958). On areas where erosion is a hazard, all seedbed preparation and drilling should be done on the contour or seeding should be done in contour furrows or terraces.

PLANTING SEED

Drilling is the best method of seeding, if the ground is sufficiently smooth and rock free, because it insures covering of seed, a well-known and essential practice for successful establishment of seedings. Rate and depth of seeding can best be controlled with a drill equipped with depth bands. Many soils require culti-packing or rolling to make a firm seedbed. Drilling into very loose soil can place seed too deep for good establishment (Gomm 1962). Press wheels on the rear of a drill can pack the soil somewhat, especially on loose soils.

Broadcasting often must be used where drilling is not possible, but covering of seed by harrow, drag, or other means should follow to get a successful stand, and seeding rates must be doubled or trebled. Sampson (1913) and Forsling and Dayton (1931) described some ingenious handmade equipment and other ways to cover seed after broadcasting, including a wooden peg "A" harrow, brush drags, and trampling by sheep following seeding. Use of livestock to trample seed into the ground to insure germination has been widely recommended since that time, and may be beneficial in some situations. One element of one of the treatments in the "rest rotation" grazing system described by Hormay and Talbot (1961) is deferment of an area until seed set, then grazing heavily to insure "planting" of seed by trampling. Little experimental evidence exists, however, to verify that this is effective on native rangelands. Hyder and others (1975) reported that the treatment is not effective for establishing new plants on shortgrass plains.

Broadcasting grass seed with no followup covering generally has met with little success on rangelands in North America, even on higher elevation mountain grasslands where precipitation is greater. In Australia, factors identified as causing failure of broadcast seeding included moisture deficiency, harvesting of seed by ants, damage by soil fauna, residual herbicides in the soil, and competition from weeds (Campbell and Swain 1973). A similar study in Washington (Nelson and others 1970) determined that depredation of seed by rodents and birds and rapidly fluctuating moisture conditions that inhibited germination and restricted penetration of seedling roots were the major factors limiting success of broadcast seedings. In Washington, Goebel and Berry (1976) found that small birds selected two small-seeded grass species in preference to larger seeded wheatgrasses. Such selective depredation could result in either a poor stand or charge the intended composition of a seeded stand, especially on broadcast seedings, but it could also cause troubles in drilled areas.

Broadcasting seeds into ashes after a burn is a standard, and usually successful, technique because the seeds sink into or are otherwise covered with ashes. Best success has been achieved when seeding was done before the first rain. Seeding has been done with hand or power broadcasters or, more commonly, by airplane or helicopter. Successful seedings resulting from this technique were reported on burns in the ponderosa pine type in Oregon (Cornelius and Talbot 1955), southern Idaho (Hull and Holmgren 1964), South Dakota (Orr 1970), and Arizona (Lavin and Springfield 1955). Similar results were obtained on burns in the spruce-fir type in Colorado (Hull and others 1958) and in lodgepole pine and Douglas-fir types in Washington (Tiedemann and Klock 1973)

A highly successful technique for seeding in the aspen type is broadcasting seed just before leaf drop. The aspen leaves cover the seed and maintain moisture conditions conducive to germination. Plummer and Stewart (1944) and Plummer and others (1955) reported this technique, using a variety of species (appendix). Hull and others (1958) reported improvement of deteriorated aspen stands in Colorado by broadcasting smooth brome, orchardgrass, timothy, and Kentucky bluegrass prior to leaf fall at a rate of 3 pounds per acre (3.4 kg/ha) for each species. Successful applications of this technique in aspen were also reported in southern Idaho by Hull and Holmgren (1964) and on the east slope of the Sierra Nevada and southern Cascade Mountains of California by Cornelius and Talbot (1955). McGinnies and others (1963) reported unsatisfactory stands resulting from broadcast seeding just after aspen leaf fall and they speculated that better stands would have been obtained if seeding had been done before leaf fall. Plummer and others (1955) also recommended broadcast seeding before leaf drop in oakbrush, maple, and serviceberry tall brush stands.

Because broadcasting seed had so little success except in the specialized situations described above, attempts have been made to coat seed with various materials or compress seed into earthern pellets to overcome the need for covering after broadcasting. Hull and others (1963) summarized information of 16 large-scale range pellets seedings, covering more than 18,000 acres (7 300 ha) in the western United States. Ten trials were complete failures and six gave unsatisfactory stands. The only high-elevation rangelands included in the summary were aspen, mountain brush, and ponderosa pine on the Manti-LaSal National Forest in southeastern Utah seeded with compressed earthern pellets broadcast from an airplane at a rate of 1.2 to 2.4 pounds of seed per acre (1.3 to 2.7 kg/ha). Seven years following seeding, aspen sites seeded with pellets produced 134 pounds of grass per acre (150 kg/ha) while stands seeded with unpelleted seed produced 251 pounds per acre (281 kg/ha). The success in both cases was attributed to covering of seed by leaf fall. Pelleted seed produced only 0.1 pounds of herbage per acre (0.1 kg/ha)

in the mountain brush type (Bleak and Phillips 1950). Chadwick and others (1969) reported successfully seeding pelleted alsike clover into weedy Thurber fescue grasslands on Black Mesa in Colorado, but the clover did not persist in the stands.

In some other grassland areas of the world, broadcast seeding is routinely used as a successful improvement technique. Good distribution and amount of rainfall undoubtedly make the technique successful, in contrast to the general failures reported in the United States. In New Zealand, improvement of high-elevation tussock grasslands has been largely done by oversowing (broadcast seeding) with improved grasses and legumes and top dressing (fertilizing) to improve inherently infertile soils. Use of airplanes for applying seed and fertilizer on lands too steep for ground equipment started after World War II (Campbell 1956).

Broadcasting grass and clover seed and fertilizer has also been successfully used to get vegetative cover on high-elevation subsoils exposed by severe erosion in New Zealand (Dunbar 1971). Soils on such areas are extremely infertile and fertilizers used generally contain many needed trace elements as well as phosphorus, nitrogen, calcium, and sulfur. Where successful stands are established on such areas, followup applications of fertilizer, especially superphosphate, usually are necessary to maintain the stand.

TIME OF SEEDING

Planting should be timed so that seeds will germinate and seedlings emerge at the beginning of the longest period of favorable soil moisture and temperature. Early studies by Plummer and Fenley (1950) indicated that spring and early summer were best for planting at high elevations. Later studies have indicated, however, that late-fall seedings often produce good stands because the seed is in place to germinate early in the spring as soon as the temperature is favorable. Generally, this is earlier than seeding equipment can be used on the area in spring because of wet soils. Fall-planted seed has a longer period of favorable moisture conditions for seedling growth in the spring than seed planted in the spring. The success of fall seeding at high elevations may be limited by soil characteristics. Complete failures from fall seeding can occur on areas where soils puddle, bake hard, or form a vesicular structure (F. B. Gomm, personal communication).

On high-elevation rangelands in northern Utah, Hull (1966) found emergence was best from seedings in September, October, and June, in that order. Seedings made too early in the fall may result in germination and subsequent frost heaving or frost kill before permanent snow cover occurs. In areas with deep snow cover, soil may thaw before snowmelt and some seeds germinate under such conditions (Bleak 1959).

DEPTH OF SEEDING

Seed should be placed at the proper depth for best germination and emergence, and this is related to seed size and seedling vigor. Planting seed too deep with a drill can result in poor emergence and not planting seed deep enough, such as in broadcasting, can leave seeds in a position deficient of moisture due to surface drying.

RATE OF SEEDING

The amount of seed needed varies with species and seeding method. Heavy rates of seeding may produce thicker stands earlier and thus protect the site from erosion, but 10 or more years after planting little difference usually is observed in stands produced as a result of different rates of seeding. In Utah and Idaho, Hull (1972) recommended that at least 12 pounds per acre (13.5 kg/ha) of pure live seed be used at high elevations in order to get a good stand within a reasonable amount of time. Cook and others (1974) recommended 7 pounds per acre (7.8 kg/ha) of pure live seed of crested wheatgrass on foothill areas drilled and at least 14 pounds per acre (15.7 kg/ha) of pure live seed when broadcast. Other investigators have used as much as 100 pounds per acre (112 kg/ha) on alpine sites using locally collected seed which had very low germinability (Brown and others 1978).

ROW SPACING

Drill row spacings usually have ranged between 6 and 24 inches (15 and 60 cm). Less seed usually is required for rows spaced further apart, but more years are required to obtain a closed stand. Close spacing may help prevent erosion and inhibit invasion by undesirable plants in the early years after seeding. Hull (1972) found little difference in herbage production from seed placed at 6- and 12-inch (15- and 30-cm) row spacings in high elevation plantings in southeastern Idaho. In the ponderosa pine zone in Arizona, Reynolds and Springfield (1953) found essentially no difference in herbage production from crested wheatgrass planted at 6-, 12-, and 18-inch (15-, 30-, and 45-cm) spacings.

MULCHES

Kay (1978) summarized some of the available information on the effect of mulches on stand establishment. He concluded that seed coverage (mulching with soil) is the single most important practice. Gates (1962) studied the effects of various mulch and fertilizer treatments on establishment of grasses on high-altitude, harsh environment sites in northern Idaho. Sawdust, evergreen boughs, and asphalt emulsion did not significantly increase establishment of planted species. Native hay, held in place by chicken wire, did result in good grass establishment, apparently as much from the seeds contained in the hay as for any other reason. Gates concluded that mulch treatments do not increase seedling emergence of seeded grasses. Other studies have indicated that mulch alone had no effect on establishment, but mulch in combination with fertilizer significantly increased stand establishment and subsequent production (Farmer and others 1976; Klomp 1968).

Various mulch treatments have been successful in seeding road cuts and other harsh sites. Cook and others (1970) found that wood fiber, straw-asphalt, jute mesh, and macerated paper mulches applied on road cuts at high elevations in Utah all provided protection to the soil surface against evaporation and erosion, produced more grass seedlings, and produced a more dense herbage cover than treatments without mulches. Chopped mature "hay" from native alpine meadows in Colorado is being investigated as a combined seed source and mulch (Ron Zuck, personal communication). More study is obviously needed on this aspect of seeding high-elevation rangelands. It may be that

relatively level range sites with only moderate disturbance will not require mulching, but areas that are heavily disturbed, raw, or without soil will require mulches for plant establishment.

PROTECTION FROM ANIMALS

Protection from big game, rabbits, rodents, and other animals may also be necessary to prevent failure of the stand. Where newly planted areas are subject to damage by rabbits and rodents, poisoned hay, grain, or salt have been effective control measures. Recent bans, however, have eliminated most poisons from use and require approval of any such operation. Use of large plantings can help avoid problems from rodents and other animals.

Pocket gophers can be one of the greatest problems where high-elevation seedings are concerned. On a high-elevation range in Utah, Julander and others (1959) reported that production of grass (timothy, orchardgrass, tall oatgrass, and smooth brome) averaged 1,270 pounds per acre (1 420 kg/ha) where gophers were controlled and only 535 pounds per acre (600 kg/ha) where they were not controlled. Garrison and Moore (1956) reported similar reductions in basal diameter of crested and pubescent wheatgrasses and tall oatgrass seedings in mountain meadows in Oregon. Both burrowing and feeding activities of the gophers were thought to be responsible for the damage to the seeded grasses in both studies. McGinnies and others (1963) reported severe damage to planted smooth brome stands in western Colorado caused by gophers burrowing down the rows and destroying the plants. Gophers can be controlled by placing poisoned bait in burrows, but the restrictions mentioned above also apply. Trapping can be effective, but is expensive. Good seedbed preparation is needed to kill the forbs that are a favored food supply, thus preventing gophers from being attracted to the seeded area (Julander and others 1959; Garrison and Moore 1956). Selection of species to be planted is also important on gopher-infested rangelands. Species able to reproduce both by seed and vegetatively, such as smooth brome and meadow foxtail, should be chosen. Unless gophers can be controlled, plants with fleshy roots, such as alfalfa and clovers, should be avoided. Eliminating native fleshy-rooted forbs by spraying with 2,4-D has also been effective in reducing pocket gopher populations (Tietjen 1973).

MANAGEMENT AFTER SEEDING

Management of livestock grazing on newly seeded areas is essential. No grazing should take place until the seedlings develop enough vigor and sufficiently large root systems to prevent uprooting and other damage from grazing. Two years of protection following seeding is commonly recommended, but this varies with area and conditions. Seeding operations should be correlated with long-term range management plans for water development, grazing systems, fencing, and other management tools. Because of differences in palatability between seeded and native species, seeded areas should be large enough to prevent damage from concentrations of either big game or livestock. Ideally, seeded areas should be large enough to manage as separate units. Plummer and others (1968) recommended that areas seeded in Utah be at least 500 acres (200 ha).

Discussion

Seeding of depleted high-elevation rangelands can markedly increase herbage production and protect sites from erosion. Costs are high, however, and the procedure is not without risk. Preparing a site for seeding usually involves removal of existing plant cover, which leaves the soil bare and vulnerable to erosion until the seeded stand becomes established. This can be especially hazardous on high-elevation areas subject to high-intensity summer storms. If enough desirable species are present in the existing vegetation so that productivity and soil protection can be improved substantially by grazing management, fertilizer, or other management tools, then seeding probably should not be attempted. If the vegetation is extremely depleted, however, or if disturbance has been so severe that the original vegetation is no longer present, the option to seed or not to seed no longer exists and a stand of the best adapted species should be planted.

In 1931, Forsling and Dayton made the following comment about species needed for seeding western rangelands:

> Thus far, work in artificial reseeding on rangelands has been confined largely to cultivated species and a few native western range plants. There are still many undeveloped possibilities such as further trials with native range plants, the search in foreign countries for plants suited to western range conditions, and the development of more suitable forms by plant breeding and selection. The success with the few native western species tried, the successful introduction into the United States of many foreign species for other purposes, and breeding up of cereals and other crop plants suggest that promising results will be attained as more attention is devoted to range forage plants.

Additional breeding, selection, and field testing have been done on some range species by the Soil Conservation Service Plant Material Centers and others. Forsling and Dayton's comments, however, are nearly as applicable today as they were in 1931.

The total area of depleted high-elevation rangeland requiring seeding is not known. Estimates made in the 1950's indicated very substantial areas in the western United States that were in depleted condition and in need of seeding, include:

Intermountain area (Plummer and others 1955). .... 20 million acres (8.1 million ha)
Montana (Short and Woolfolk 1952) .... 3 million acres (1.2 million ha)
Ponderosa pine zone in Colorado (Hull and Johnson 1955) .... 500,000 acres (202 000 ha)
Summer ranges in Oregon and Washington (Rummell and Holscher 1955) .... 600,000 acres (243 000 ha)
Plateau region of northeastern California (Cornelius and Talbot 1955) .... 500,000 acres (202 000 ha)

The last three of these references refer specifically to high-elevation rangelands. There are, however, substantial acreages of high-elevation areas included in the estimates from Montana and the Intermountain area. Only a small

fraction of the indicated area has been seeded since the 1950's, but some areas have undoubtedly been improved by better management systems.

The inventory of the nation's range resources compiled by the Forest-Range Task Force (1972) indicated that more than 72 percent of the nonforested western range area was in poor-to-fair condition, with 98 percent of the alpine zone in poor condition, 58 percent of the mountain meadows in poor-to-fair condition, and 55 percent of the mountain grasslands in poor-to-fair condition. I feel that these estimates of depleted rangelands are substantially too high for these types because of inadequate or improper condition criteria. It does appear, however, that the need for seeding large areas of high-elevation rangelands to increase productivity and soil stability still exists.

FERTILIZING

Reasons for Fertilizing

High-elevation rangelands have been fertilized mainly to increase production of palatable species for livestock. Other reasons for fertilization have been to: increase palatability, increase nutrient quality, extend the period of green growth, influence distribution of livestock, increase emergence and survival of seeded species, hasten improvement of deteriorated areas, and renovate unproductive senescent stands of seeded grasses.

Use of fertilizers on grasslands often has high appeal compared to some other methods because of the ease of application, minimal soil disturbance, immediate visual response in some cases, and generally no deferment period following application (Ryerson and Taylor 1975).

Ryerson and Taylor (1975) outlined two approaches in using fertilizers on rangeland. The first approach is the one most commonly used on high-elevation rangelands and focuses on stimulating increased production from species already present without destroying the natural multispecies complex. The second approach attempts to maximize productivity by repeated applications of fertilizer. This favors species that can best respond and survive under fertilization and, if carried on long enough, can drastically change species composition.

Retzer (1954) pointed out that plants will respond to fertilizer when the fertility status of the soil is low or unbalanced. Tests usually are needed to determine fertilizer needs, but even these will not ensure response because soil moisture and other environmental factors must not be limiting if a response to fertilizer is to occur.

Duncan and Hylton (1970) reviewed the effects of fertilizer on quality of range forage and found generally conflicting evidence because of great variability in climate, soils, growth habits, state of maturity at harvest, methods of sampling, plant parts sampled, and the descriptive units in which results were reported. They concluded that nitrogen (N) probably has improved forage quality more consistently than any other type of fertilization, resulting in increased crude protein, increased succulence, increased leaf-to-stem ratios, and extended periods of green growth.

Williams (1972) reviewed the role of fertilizers in wildlife management. He concluded that fertilizer, especially nitrogen, influences production, nutrient content, and palatability of plants consumed by wild animals, but that little was known about how such changes in the plants affect game populations.

Results of Fertilizer Trials

Results of fertilizer trials on high-elevation rangelands are summarized below. Fertilizer trials on irrigated or flooded mountain meadows have not been included.

Results from fertilizer trials on mountain rangelands have varied, ranging from no response to significant response. In studies to determine effects on production, where responses have been found, the effective fertilizer usually has been nitrogen. Pot tests of soils from 10,200 to 10,600 feet (3 110 to 3 230 m) in the Medicine Bow Mountains in southeastern Wyoming indicated that the soils tested were deficient in available phosphorus (Smith 1966). Phosphorus (P) fertilizer, however, has produced increases in few field studies, but combinations of N plus P have produced additive effects in some studies. Potassium generally is not limiting in western soils and ordinarily is not included in fertilizer trials.

Retzer (1954) studied response to fertilizer of the vegetation on seven soils from the ponderosa pine and spruce zones in Colorado. Nitrogen applied at 32.5 pounds per acre (36 kg/ha) increased herbage on soils from granitic materials for 1 to 2 years after application. No response to N fertilization was found on soils derived from basalt and andesite. Responses to P, K, and minor element fertilization were inconclusive.

On Idaho fescue ranges in the Bighorn Mountains of Wyoming, Lang (1956) found no increase in forage production following nitrogen fertilization in the form of urea at a rate of 67.5 pounds per acre (76 kg/ha). The fertilized areas, however, were used much more heavily by cattle than adjacent unfertilized areas, which were grazed only slightly (Smith and Lang 1958). In a followup fertilization study, nitrogen was applied at rates of 0, 25, 50, 75, and 100 pounds per acre (0, 28, 56, 84, and 112 kg/ha) in the form of ammonium nitrate. In the year following application, yield of grasses increased about 150 pounds per acre (168 kg/ha) for the 25 to 50 pounds per acre (28 to 56 kg/ha) nitrogen applications, and only slightly higher increases in yield occurred at the 75 and 100 pounds per acre (84 and 112 kg/ha) rates. Although the increase in grass production was statistically significant, it did not approach economic feasibility. Increases in forb production followed a similar pattern but on a much smaller scale. Crude protein content of Idaho fescue plants was increased by all applications of nitrogen fertilizer, but the maximum rate of increase was with the application of 25 pounds per acre (28 kg/ha) of nitrogen. At higher levels of nitrogen further increases in protein were small. In the same area, Smith and Lang (1962) reported the results of joint applications of 2,4-D and fertilizer at rates of 0, 50, 100, and 200 pounds per acre of nitrogen (0, 56, 112, and 224 kg/ha). Maximum increase in grass production was obtained with 200 pounds per acre (224 kg/ha) of nitrogen in combination with the herbicide, but the practice was not economically feasible

On Idaho fescue grasslands in northeastern Oregon, Baldwin and others (1974) found that fertilization at very high rates markedly increased forage production (table 2). In the 4 years following application of 297, 594, and 1,188 pounds (333, 666, and 1 332 kg/ha) of 27-12-0 fertilizer, the fertilized plots produced an average of 4,220 pounds per

acre (4 730 kg/ha) per year, while the unfertilized plots averaged 1,480 pounds per acre (1 660 kg/ha). The three rates of fertilizer did not differ significantly in production. All levels of fertilization increased the lengths of the green forage season by about 6 weeks, and temporarily increased nitrate nitrogen in the forage. Nitrate levels at the two highest rates of fertilization were in the toxic range for a short period of time. All rates of fertilization increased the proportion of the introduced grass, Kentucky bluegrass, in the composition. No analysis was made of the economic feasibility of this high rate of fertilization.

On green fescue (*Festuca viridula*) grassland in Washington, Smith (1963) reported that 200 pounds per acre (224 kg/ha) of ammonium sulphate applied the year 14 different grasses were seeded resulted in more grass production than on unfertilized plots the year following seeding. The amount of the increase was not quantified and no response from the fertilizer was evident 3 years after seeding. Superphosphate applied shortly after planting at the rate of 200 pounds per acre (224 kg/ha) on plots planted to various legumes had no effect on establishment or production of any species.

On a Columbia and Richardson needlegrass (*Stipa columbiana* and *S. richardsonii*) grassland site in British Columbia, nitrogen fertilization up to 100 pounds per acre (112 kg/ha) did not increase productivity significantly, but phosphorus applied at 60 pounds per acre (68 kg/ha), both alone and in combination with nitrogen, did increase productivity slightly (Hubbard and Mason 1967) (table 2). These grassland areas were originally a rough fescue and beardless wheatgrass association.

On ponderosa pine-Arizona fescue range in Arizona, Lavin (1967) reported that one fall broadcast application of 33, 66, or 99 pounds per acre (37, 74, or 111 kg/ha) of nitrogen per acre increased herbage production of intermediate wheatgrass for four growing seasons. Increases the first growing season were the greatest (table 2). Production from the 99 pounds per acre (111 kg/ha) application, however, did not significantly differ from production at the 66 pounds per acre (74 kg/ha) of nitrogen in any year. Phosphorus alone, or in combination with nitrogen, did not increase production.

In the ponderosa pine zone in Colorado, McGinnies (1968) applied nitrogen at five rates up to 100 pounds per

Table 2.--Comparison of peak aboveground standing crop on fertilized and unfertilized high-elevation rangeland areas

Location	Type of high-elevation rangeland	Type	Rate		Yield of grasses years following fertilization: 1 year		2 years		3 years	
			Lb/acre	*Kg/ha*	*Lb/acre*	*Kg/ha*	*Lb/acre*	*Kg/ha*	*Lb/acre*	*Kg/ha*
Northeastern Oregon	Idaho fescue	Control	0	0	1,042	1 168	1,638	1 836	1,613	1 808
(Baldwin and others		27+12	297	333	4,667	5 232	3,965	4 445	3,192	3 578
1974)		(N+P)	594	666	4,875	5 465	5,436	6 094	2,636	2 955
		plus 4%S	1,188	1 332	2,979	3 339	5,326	5 970	2,874	3 191
British Columbia	Needlegrass (origi-	Control	0	0	656	735	455	510	1,279	1 444
(Hubbard and	nally rough fescue)	N	100	112	673	754	498	558	1,325	1 485
Mason 1967)		P_2O_5	60	68	778	872	479	537	1,546	1 733
		(N+P)	(60+60)	(68+68)	892	1 000	519	582	1,486	1 666
Northern Arizona	Ponderosa pine-	Control	0	0	887	994	972	1 090	430	482
(Lavin 1967)	Arizona fescue seeded	N	33	37	1,394	1 563	1,233	1 382	456	511
	to intermediate	N	66	74	2,025	2 270	1,493	1 674	498	558
	wheatgrass	N	99	111	2,080	2 332	1,666	1 867	510	572
Colorado	Ponderosa pine-	Control	0	0	1,044	1 170	1,124	1 260	546	612
(Currie 1976)	Arizona fescue[1]	(N+P+K)	(50+50+40)	(56+56+45)	2,110	2 365	1,628	1 825	686	769
Colorado	Ponderosa pine	Control	0	0	289	324	617	692	595	667
(McGinnies 1968)	seeded to crested	N	20	22	489	548	673	754	616	690
	wheatgrass	N	80	90	781	876	966	1 083	633	910
		N	160	180	767	860	1,103	1 236	867	972
		N	400	449	748	839	1,657	1 857	1,302	1 460
Southwestern Utah	Openings in spruce-	Control	0	0	470	527	1,212	1 358	--	--
(Bowns 1972)	fir	N	60	68	728	816	1,862	2 087	--	--
		P	60	68	628	704	1,777	1 992	--	--
		(N+P)	(60+60)	(68+68)	836	937	1,972	2 211	--	--
Northeastern Utah	Openings in spruce-	Control	0	0	5,159	5 783	5,148	5 771	--	--
(Hull 1963)	fir seeded to	N	100	112	5,483	6 146	4,867	5 456	--	--
	pubescent wheatgrass	N	200	224	4,882	5 473	4,820	5 403	--	--
		N	600	672	5,285	5 924	4,961	5 561	--	--
		P_2O_5	200	224	5,428	6 085	5,218	5 849	--	--
		(P+N)	(200+100)	(224+112)	5,487	6 151	5,171	5 797	--	--
Northern Utah	Native mountain	Control	0	0	943	1 057	--	--	--	--
(Cook 1965)	meadows	N	80	90	1,442	1 617	--	--	--	--
		P	80	90	1,092	1 224	--	--	--	--
		(N+P)	(80+80)	(90+90)	1,880	2 107	--	--	--	--

[1]Figures include both grasses and forbs.

acre (112 kg/ha) annually and biannually for 6 years to an old stand of crested wheatgrass. Unfertilized plots declined in vigor, but as little as 20 pounds per acre (22 kg/ha) applied annually appeared to prevent stand deterioration. Total average herbage yield was highest at the 60, 80, and 100 pounds per acre (68, 90, 112 kg/ha) rates. In another experiment a one-time application of N was applied at nine rates up to 400 pounds per acre (449 kg/ha). The 10 and 40 pounds per acre (11 and 45 kg/ha) rates increased herbage yield in the first year; the 60 to 200 pounds per acre (68 to 224 kg/ha) rates increased yield through the third year; and the 400 pounds per acre (449 kg/ha) rates increased yield through the fourth year. No rate had any effect by the fifth year. On depleted native range McGinnies (1962) found that N increased production of undesirable species but had no effect on desirable species.

Studies of native grasslands in the ponderosa pine type in Colorado (Currie 1976) have shown that 50 pounds per acre (56 kg/ha) of elemental material of each fertilizer (nitrogen, phosphorus, and potassium) provides excellent response and will increase total herbage yield 500 to 1,000 pounds per acre (560 to 1 200 kg/ha) the first 3 years following fertilizer application (table 2).

Improvement of production of the more desirable bunchgrasses was obtained by spraying depleted areas with 2.5 pounds per acre (2.8 kg/ha) acid equivalent of 2,4-dichlorophenoxy acetic acid to reduce production of the less desirable forbs. Application of a complete fertilizer, in combination with the herbicide treatment, enhanced growth of the residual grass plants.

Fertilization was also used on Sherman big bluegrass stands in the same area to modify the root growth of this species and reduce the ease with which this species is pulled up by grazing cattle. Nitrogen or phosphorus alone reduced the tensions required to pull the plants, but NP together made pulling more difficult than pulling of plants receiving no fertilizer treatment. Evaluation of plant root systems and top growth in glass-faced planter boxes indicated a close correlation between the total root system weight and the tension required to pull the plants (Haferkamp and Currie 1973).

On native subalpine parks at an elevation of 10,200 ft (3 110 m) in southwestern Utah, Bowns (1972) found significant increases in production for 2 years from a single application of nitrogen and phosphorus (table 2). Rates of application were 30 and 60 pounds per acre (34 and 68 kg/ha) of nitrogen and phosphorus, alone or in combination. The highest production was obtained from a combined application of 60 pounds per acre (68 kg/ha) of the two elements. The average production increase from adding 60 pounds per acre (68 kg/ha) of phosphorus to the 60 pounds per acre (68 kg/ha) of nitrogen, however, was only about 100 pounds per acre (112 kg/ha) more than the increased production from adding that amount of nitrogen alone. Crude protein content of the plants was increased only the first year following applications of all levels of nitrogen fertilizer, with or without phosphorus. Phosphorus applications had no effect on crude protein content. All levels of phosphorus fertilizer increased the phosphorus content in forage for 3 years following application. The dominant herbaceous species were bistort (*Polygonum bistortoides*), western yarrow (*Achillea lanulosa*), bluegrass (*Poa canbyi*), tufted hairgrass (*Deschampsia caespitosa*), spike trisetum (*Trisetum spicatum*), alpine timothy, and letterman needlegrass (*Stipa lettermanii*).

On native mountain meadows in northern Utah, Cook (1965) found that nitrogen and phosphorus, singly and together, applied for 3 consecutive years significantly increased herbage yield. Nitrogen alone, at 80 pounds per acre (90 kg/ha), increased forb production by 240 pounds per acre (270 kg/ha) and grass production by 500 pounds per acre (560 kg/ha) (table 2). Phosphorus alone had a smaller effect, but nitrogen and phosphorus together appeared to have an additive effect, since 80 pounds per acre (90 kg/ha) of nitrogen plus 80 pounds per acre (90 kg/ha) of phosphorus increased total yield of grass and forbs from 1,479 pounds per acre (1 658 kg/ha) to 2,245 pounds per acre (2 517 kg/ha).

On unirrigated mountain meadows in Utah seeded to smooth brome, nitrogen applied at either 40 or 80 pounds per acre (45 or 90 kg/ha) increased yield more than 1,000 pounds per acre (1 120 kg/ha) the year following application, but the increase dropped to about 100 pounds per acre (112 kg/ha) the second year (Cook 1965). Total protein content of the grass was significantly higher on the fertilized area for the first and second years following fertilization.

Cook (1965) also reported that applications of 60 pounds per acre (67 kg/ha) of nitrogen increased palatability of forage on native mountain slopes. This induced heavier grazing on these areas. He suggested that this is a way to increase use of poorly utilized areas but emphasized that fertilization had to be combined with proper moving of cattle to make best advantage of the increased palatability.

Hooper and others (1969) made a preliminary economic analysis of the use of fertilizer to improve livestock distribution on aspen and mountain sagebrush ranges in northern Utah. The fertilized areas produced 2,160 pounds of forage per acre (2 402 kg/ha) while control areas produced 1,580 pounds per acre (1 770 kg/ha). The increase in yield did not pay the cost of fertilizing. Increased utilization, however, for 2 years following fertilization, increased grazing capacity enough to cover the costs. They cautioned that fertilizer should not be placed where animals normally congregate and that areas should be sufficiently large (at least 30 acres [12 ha]) so that excessive use would not occur.

On high elevation mountain grassland parks in Montana, Gomm (1962) found that 100 and 200 pounds per acre (112 and 224 kg/ha) of nitrogen or phosphorus alone, and in combination, applied at the time of seeding had no effect upon the number of seedlings of meadow foxtail, smooth brome, and Kentucky bluegrass established. Heavy grazing by sheep destroyed the stands and prevented further evaluation. Annual precipitation in the area was about 25 inches (64 mm). In a greenhouse study, using soils from the same areas, the same rates of fertilizer increased growth of grass after the third leaf stage. Crested wheatgrass and orchardgrass responded the most, tall fescue responded in an intermediate fashion, and timothy responded the least to fertilizer.

On disturbed sites on lodgepole pine, Douglas-fir, and subalpine fir types in Washington, ammonium phosphate sulfate fertilizer applied at a rate of 48 pounds per acre (54 kg/ha) of N and 60 pounds per acre (67 kg/ha) of P increased emergence, establishment, and ground cover in

individual grass species trials. Mixtures of species, however, did not form satisfactory stands either with or without fertilizer (Klock and others 1975).

On high elevation stands of pubescent wheatgrass seeded into openings in a spruce-fir stand in northern Utah (elevation 7,700 ft, [2 350 m]), Hull (1963) found no significant increase in grass production 5 years after seeding. Twenty, forty, and sixty pounds per acre (22, 45, and 68 kg/ha) of nitrogen (ammonium nitrate) and 200 pounds per acre (224 kg/ha) of phosphorus (treble superphosphate) were applied singly or in combination the previous spring or fall. Annual precipitation in the area was approximately 32 inches (81 cm). In the same general area, but at 8,400 feet (2 560 m) elevation, fertilizer applied at the time of seeding did not significantly affect the number of seedlings of intermediate wheatgrass, slender wheatgrass, pubescent wheatgrass, smooth brome, or hard fescue emerging or plants surviving after 3 years.

In the same area, Hull (1963) also reported that nitrogen and phosphorus fertilizer applied both in the spring and fall 3 years after seeding timothy, meadow foxtail, smooth brome, tall oatgrass, orchardgrass, and intermediate wheatgrass had no significant effect on herbage production (table 2). Nitrogen applied at 100, 200, and 600 pounds per acre (112, 225, and 672 kg/ha) in October was not found in the soil as nitrate nitrogen the following year. Nitrogen applied in May was found only in the top 6 in (15 cm) of soil in August. Hull concluded that the nitrogen was probably leached by the 30 to 40 in (76 to 102 mm) of water from late-fall rain and snowmelt. Complete leaching, however, did not take place because all levels of nitrogen fertilizer increased protein content of the grass.

Berg and Barrau (1978) reported that addition of 60 pounds (68 kg/ha) of N annually for 2, 3 or 4 years substantially increased the ground cover of seeded grasses on exposed glacial till at high-elevation sites in Colorado.

Use of Legumes to Increase Nitrogen in Soils

It is generally assumed that legumes increase nitrogen content of the soil and increase herbage production, but few definitive studies have been carried out on rangeland areas. On high-elevation wet meadows seeded to smooth brome, orchardgrass, meadow foxtail, timothy, reed canarygrass, and intermediate wheatgrass, presence of alsike clover was almost as effective as 200 pounds per acre (225 kg/ha) of nitrogen for increasing yield. The clover, however, did not persist in the stands after 2 years (Grable and others 1965).

Cook and others (1970) reported that red and alsike clovers and vetches (*Vicia* spp.) helped maintain vigor of grasses seeded on high-elevation road cuts in Utah because of the added nitrogen.

Bleak (1968) tested nine different legumes in mixtures with various grasses on mountain rangelands in central Utah. Cicer milkvetch and three varieties of alfalfa (A-169, Ladak, and Rhizoma) did well and increased total production of the stand an average of 144 pounds per acre (161 kg/ha). Compared with pure grass stands, flat peavine (*Lathyrus sylvestris*), perennial milkvetch, sickle milkvetch (*Astragalus falcatus*), birdsfoot trefoil, and Siberian alfalfa (*Medicago falcata*) either died out completely or formed poor stands. Smith (1963) reported good stands of birdsfoot trefoil, flat peavine, and perennial milkvetch 3 years after planting on green fescue grasslands in Washington. In the same study, sainfoin (*Onobrychis viciaefolia*), Nomad, Ladak, and Sevelra alfalfas, and cicer milkvetch failed to establish stands.

Heinrichs (1975) stated that legumes can play an important role in increasing production of rangelands in North America. However, much research is needed in breeding, selection, and management. Legumes planted with grasses on mountain rangelands often have not persisted in the stands because of selective grazing and for other reasons.

In Colorado, cicer milkvetch was the only introduced legume to maintain stands after 10 years at 11,000 ft (3 350 m). At 9,000 to 10,000 ft (2 740 to 3 050 m), alfalfa and alsike clover established well and made good growth (Berg and Barrau 1978).

Use of Manure as Fertilizer

No studies were found in which barnyard manure had been used as fertilizer on high-elevation rangelands. Manure has been used successfully, however, to increase yields of grasses on other grassland types. On shortgrass prairie in Canada, plots receiving one application of 12 tons per acre (27 t/ha) of manure still produced more than twice as much forage as did untreated areas 11 years after application (Clarke and others 1943). Similar results were reported in the northern Great Plains (Heady 1952; Lodge 1959; and Smoliak 1965) and on shortgrass plains in Colorado (Klipple and Retzer 1959). Research is needed on this method of improving mountain grasslands.

Discussion

It is apparent that fertilization of high-elevation rangelands, especially with nitrogen, can result in increased production; but conditions necessary for success are not well understood or consistent. Even when success is achieved, the economic feasibility is often questionable or negative. Increases in palatability, higher protein content, change in species composition, and longer season of green growth, however, often are results of fertilization that are not taken into account in an economic analysis.

Cook (1965) concluded that herbage on most range soils will respond to nitrogen fertilization. He noted, however, that before extensive areas are treated on a practical scale, tests should be made on small plots to see if the benefits received will justify the cost. Schlatterer (1974) was less enthusiastic. "The high cost of fertilizer and application, the lack of consistent year-to-year production increases, and the lack of consistent carryover of production increases from one year to the next over an extended period on grazed sites, raise a question as to the economic practicability of using nitrogen fertilizer to increase production on rangelands in the Intermountain Region." Rather large increases in the cost of fertilizer in the past several years perhaps make this observation even more meaningful. Gomm (1962) concluded that "More basic information on the rates of application of fertilizer is needed to determine the effectiveness of fertilizer for aiding establishment of seeded grasses on severely depleted rangelands." This need for further research is still true both for fertilizer used to help establishment of seedings and for fertilizer used to increase production.

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APPENDIX

Species Recommended for Planting on Mountain Grasslands and Other High-Elevation Rangelands

Pages 18 and 19

Appendix 1.--Species recommended for planting on mountain grasslands and other high elevation rangelands

SPECIES[1]	FESCUE GRASSLANDS: Thurber fescue in Colorado (McGinnies, and others 1963)	FESCUE GRASSLANDS: Green fescue in Washington (Smith 1963)	OPENINGS OR BURNS IN HIGH ELEVATION FORESTS, MOUNTAIN HERBLANDS: Forsling and Dayton 1931: Inland mountains - medium to high elevation below timberline	Forsling and Dayton 1931: Inland mountains - near timberline	Forsling and Dayton 1931: West coastal slope - mountains	Colorado (Hull, Hervey, Doran and McGinnies 1958)	Utah (Plummer, Christensen, and Monsen 1968)	Southern Idaho (Hull and Holmgren 1964)	Montana (Short and Woolfolk 1952)	Utah, Nevada, So. Idaho & Western Wyoming (Plummer and others 1955)	Idaho, Utah, and Wyoming (Hull 1974)	Eastern Oregon and Washington (Rummell and Holscher 1955)	East slope Sierra and Southern Cascades (Cornelius and Talbot 1955)	MOUNTAIN MEADOWS: Utah (Plummer, Christensen, and Monsen 1968)	Southern Idaho (Hull and Holmgren 1964)	Montana (Gomm 1962)	Eastern Oregon and Washington (Rummell and Holscher 1955)	East slope Sierra Nevada and South Cascades (Cornelius and Talbot 1955)	ASPEN: Colorado (Hull, Hervey, Doran, and McGinnies 1958)	Utah (Plummer, Christensen, and Monsen 1968)	Southern Idaho (Hull and Holmgren 1964)	Utah, Nevada, South. Idaho and Western Wyoming (Plummer et al. 1955)	Intermountain Region (Plummer and Stewart 1944)	East slope Sierra Nevada and South Cascades (Cornelius and Talbot 1955)	PONDEROSA PINE: Colorado (Hull and Johnson 1955)	Colorado (Hull, Hervey, Doran and McGinnies 1958)	Colorado (McGinnies, et al. 1963)	Southern Idaho (Hull and Holmgren 1964)	Eastern Oregon and Washington (Rummell and Holscher 1955)	East slope Sierra Nevada and South Cascades (Cornelius and Talbot 1955)
GRASSES																														
Agrostis alba (red top)	-	-	X	X	X	-	-	-	-	-	-	-	-	X	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-
Agropyron cristatum (fairway wheatgrass)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	X	X	X	-	X
Agropyron dasystachyum (thickspike wheatgrass)	-	-	X	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Agropyron desertorum (crested wheatgrass)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	X	X	X	X	X
Agropyron inerme (beardless wheatgrass)	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	X	X	-	X	-
Agropyron intermedium (intermediate wheatgrass)	X	X	-	-	-	X	X	X	X	-	X	-	-	-	X	-	X	-	-	X	X	X	-	-	X	X	X	X	X	X
Agropyron repens (quackgrass)	X	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Agropyron smithii (western wheatgrass)	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	X	X	-	-	-
Agropyron spicatum (bluebunch wheatgrass)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-	X	X	-	-
Agropyron subsecundum (bearded wheatgrass)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	X
Agropyron trachycaulum (slender wheatgrass)	X	X	X	X	-	-	-	X	-	-	-	-	-	-	-	X	-	-	-	-	-	-	X	X	X	-	X	X	-	-
Agropyron tricophorum (pubescent wheatgrass)	-	X	-	-	-	-	-	X	X	-	X	X	-	-	-	-	-	-	-	-	-	-	-	-	X	-	X	X	X	-
Alopecurus arundinaceus (creeping foxtail)	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Alopecurus pratensis (meadow foxtail)	X	-	-	-	-	X	X	X	-	X	X	-	-	X	X	X	X	X	-	X	X	X	-	-	-	-	-	-	-	-
Arrhenatherum elatius (tall oatgrass)	X	-	-	-	-	-	X	X	X	X	X	-	-	-	-	-	-	-	-	X	X	X	X	X	-	-	-	X	X	-
Bromus biebersteinii (Regar brome)	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Bromus carinatus (mountain brome)	X	-	X	X	-	-	X	X	X	X	X	X	-	-	-	X	-	-	-	X	-	X	X	X	X	-	-	-	-	X
Bromus erectus (meadow brome)	-	X	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	X	-	-	X	-	-
Bromus inermis (smooth brome)	X	-	X	X	-	X	X	X	X	X	X	-	-	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Bromus tomentellus (subalpine brome)	-	-	-	-	-	-	X	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dactylis glomerata (orchardgrass)	X	X	X	-	X	-	X	X	X	X	X	X	-	-	-	X	-	-	X	X	X	X	X	X	-	-	-	X	X	-
Elymus glaucus (blue wildrye)	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-	X	-	-	-	-	-
Elymus junceus (Russian wildrye)	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	X	X	-	-	-
Festuca arizonica (Arizona fescue)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	X	X	-	-	-
Festuca arundinacea (tall fescue)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	X	-	-	-	-	-	-	-	-	-	-	-	-
Festuca elatior (meadow fescue)	-	-	X	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Festuca idahoensis (Idaho fescue)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-
Festuca ovina (sheep fescue)	X	-	X	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-	X	-	-	-
Festuca ovina var. *duriuscula* (hard fescue)	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-	X	-
Festuca rubra (red fescue)	X	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Festuca rubra var. *commutata* (Chewings fescue)	X	-	-	-	-	-	-	X	-	-	-	-	X	-	X	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-
Festuca thurberi (Thurber fescue)	X	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Lolium multiflorum (Italian ryegrass)	-	-	X	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Muhlenbergia montana (mountain muhley)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-
Phalaris arundinacea (reed canarygrass)	X	-	-	-	-	X	X	-	-	X	X	-	-	X	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-
Phleum pratense (timothy)	X	X	X	-	X	X	-	X	X	X	X	X	-	X	X	-	X	X	X	-	X	X	X	X	-	-	-	X	X	X
Poa ampla (big bluegrass)	-	X	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-	X	-	-	-
Poa bulbosa (bulbous bluegrass)	-	-	-	-	X	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Poa compressa (Canada bluegrass)	-	-	X	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Poa pratensis (Kentucky bluegrass)	X	-	X	X	-	X	-	-	-	-	-	-	-	-	-	X	-	-	X	X	-	-	-	-	-	X	X	-	-	-

FORBS																														
Agastache urticifolia (horsemint)	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Astragalus cicer (cicer milkvetch)	-	-	-	-	-	-	X	-	-	X	-	-	-	-	-	-	-	-	-	X	-	X	-	-	-	-	-	-	-	-
Astragalus falcatus (chickpea milkvetch)	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-
Coronilla varia (crownvetch)	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Heracleum lanatum (common cowparsnip)	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-
Lotus corniculatus (birdsfoot trefoil)	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Lupinus alpestris (mountain lupine)	-	-	-	-	-	-	X	-	-	X	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-
Lupinus sericeus (silky lupine)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-
Medicago hispida (burclover)	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Medicago lupulina (black medic)	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Medicago sativa (alfalfa)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	X	X	-	-
Medicago sativa (alfalfa) Ladak	-	-	-	-	-	-	X	-	-	-	X	-	-	-	-	-	X	-	-	X	-	X	-	-	-	-	-	-	X	-
Medicago sativa (alfalfa) Nomad	-	-	-	-	-	-	-	-	-	-	X	X	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	X	-
Melilotus officinale (yellow sweetclover)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-
Osmorhiza occidentalis (sweet anise)	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-
Sidalcea oregana (Oregon checkermallow)	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Trifolium fragiferum (Strawberry clover)	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Trifolium hybridum (alsike clover)	-	-	X	-	-	-	-	-	-	X	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Trifolium pratense (red clover)	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Trifolium repens (white clover)	-	-	X	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Vicia cracca (bird vetch)	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Vicia tenuifolia (perennial vetch)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-
Viguiera multiflora (showy goldeneye)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-
SHRUBS																														
Chrysothamnus nauseosus (rubber rabbitbrush)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-
Chrysothamnus viscidiflorus (yellowbrush)	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Purshia tridentata (antelope bitterbrush)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-
Symphoricarpos oreophilus (mountain snowberry)	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-	-	-	X	-	-	-	-	-	-	-	-	-	-

[1]Nomenclature follows Plummer and others (1977)

Laycock, William A.
1982. Seeding and fertilizing to improve high-elevation rangelands. USDA For. Serv. Gen. Tech. Rep. INT-120, 19 p. Intermt. For. and Range Exp. Stn., Ogden, Utah 84401.

This paper summarizes the available literature on seeding and fertilizing high-elevation rangelands to assist those now charged with revegetating or increasing productivity on such areas and also as an aid to further research.

KEYWORDS: seeding, fertilizing, range improvement, high elevation, productivity,

The Intermountain Station, headquartered in Ogden, Utah, is one of eight regional experiment stations charged with providing scientific knowledge to help resource managers meet human needs and protect forest and range ecosystems.

The Intermountain Station includes the States of Montana, Idaho, Utah, Nevada, and western Wyoming. About 231 million acres, or 85 percent, of the land area in the Station territory are classified as forest and rangeland. These lands include grasslands, deserts, shrublands, alpine areas, and well-stocked forests. They supply fiber for forest industries; minerals for energy and industrial development; and water for domestic and industrial consumption. They also provide recreation opportunities for millions of visitors each year.

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